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WTC-related exposures among Pregnant Women

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Abbreviations:
WTC – World Trade Center. PAH - polycyclic aromatic hydrocarbons. PCB - polychlorinated biphenyls. PCDD – polychlorinated dibenzodioxin. PCDF— polychlorinated dibenzofuran. OCDD – octachlorodibenzodioxin. PBDE-polybrominated diphenylether. 9/11 – 9/11/2001. EPA - Environmental Protection Agency. DNA – deoxyribonucleic acid. PM – particulate matter. EI – exposure index. GIS — geographic information system. LD – limit of detection. HRGC/ID-HRMS- high-resolution gas chromatography/isotope-dilution high-resolution mass spectrometry . SPE - solid phase extraction. RAMS - Regional Atmospheric Modeling System. HYPACT - Hybrid Particle and Concentration Transport. MENTOR- Modeling ENvironment for Total Risk. CDC- Centers for Disease Control and Prevention. OC- organochlorine. NHANES— National Health and Examination Study.

OUTLINE:

ABSTRACT

We have characterized environmental exposures among 187 women who were pregnant and were at or near the World Trade Center (WTC) on or soon after, September 11, 2001 (9/11), and who are enrolled in a prospective cohort study of health effects. Exposures were assessed by estimating time spent in 5 zones around the WTC and by developing an exposure index (EI) based on plume reconstruction modeling. The daily reconstructed dust levels were correlated with PM2.5 ($r=0.68$) or PM10 ($r= 0.73$-0.93) levels reported from 9/26-10/8/2001 at 4 of 6 sites near the WTC whose data we examined. Biomarkers were measured in a subset. Most (71%) of these women were located within eight blocks of the WTC at 9 a.m. on 9/11, and 12 women were in one of the two WTC towers. Daily EIs were determined to be highest immediately after 9/11 and became much lower but remained highly variable over the next 4 weeks. The weekly summary EI was associated strongly with women's perception of air quality from week-2 to week-4 after the collapse ($p<0.0001$). The highest levels of polycyclic aromatic hydrocarbons –deoxyribonucleic acid (PAH-DNA) adducts were seen among women whose blood was collected sooner after 9/11, but levels showed no significant associations with EI or other potential WTC exposure sources. Lead (Pb) and cobalt (Co) in urine were weakly correlated with ΣEI, but not among samples collected closest to 9/11. Plasma OC levels were low. Median PCB (sum of PCBs 118, 138, 153, 180) was 84 ng/g lipid and had a non-significant positive association with ΣEI ($p>0.05$). 1234678-Heptachlorodibenzodioxin levels (median 30 pg/g lipid) were similar to those levels reported in WTC-exposed firefighters but were not associated with EI. This report indicates intense bystander exposure after the WTC collapse and provides information about nonoccupational exposures among a vulnerable population of pregnant women.

INTRODUCTION

Depending upon the World Trade Center (WTC)-source characteristics and the date post September 11, 2001 (9/11), emissions from the WTC site during September 2001 through early 2002 in lower Manhattan as well as immediately adjacent areas in Brooklyn and New Jersey were affected by the WTC plume. Environmental and personal air monitoring, dust analyses, and biomonitoring have identified significant elevations in dust and air to particulates and fibers, alkaline dust, and polycyclic aromatic hydrocarbons (PAH), which were greatly elevated in the first days post 9/11, with some contaminants remaining above background for 1-3 months (Lioy et al. 2002; Lioy et al. 2004; McGee et al. 2003; Swartz et al. 2003). Higher atmospheric levels, compared with contemporaneous measures in mid-Manhattan or pre-9/11, have been found for a number of chemicals, including volatile hydrocarbons (benzene, xylene, tetrachloroethylene), metals (lead [Pb], antimony [Sb]), semi- and non-volatile chlorinated hydrocarbons (e.g. PCDF) (Lioy et al. 2002; Offenberg et al. 2003). Individual exposures have been assessed among firefighters and construction workers, who were working close to the site on and after 9/11 (Edelman et al. 2003). However, bystander exposures have not been described, although adverse health effects have been reported (Trout et al. 2002). Air-monitoring data for both particulate mass (e.g. **Figure 1**) and PAH Landrigan et al. 2004; Thurston et al. 2003showed elevations within the first month after 9/11, with intermittent excursions after that ascribed to meterologic conditions as well as operational changes at the site (Dalton 2003).

We have characterized and estimated WTC-related exposures among 187 women who were pregnant and were at or near the WTC on 9/11 or within the next three weeks. A preliminary report on birth outcomes in this group has been published (Berkowitz et al. 2003b).

Materials and methods

In 2002, we established a prospective epidemiologic study of 187 women who were pregnant and located within or near the WTC on or about 9/11. The great majority of the women recruited to this study were self-referred on the basis of extensive media publicity surrounding our investigation. Additional participants were located by sending letters to nearly 3000 obstetricians in the greater New York City area, distributing flyers in lower Manhattan, and advertising in local newspapers. Eligibility criteria were pregnancy on September 11, 2001 or shortly thereafter and presence in one of five “exposure” zones at or near the WTC at 9 a.m. (n=170) on that day or within the next three weeks (n=17). The five exposure zones were: 1) Area including and surrounding the WTC site bordered by Murray Street (N), Nassau Street (E), the Battery (S), and the Hudson River (W); 2) Area of Manhattan south of Chambers Street excluding Zone 1; 3) South of Canal Street and North of Chambers Street; 4) Brooklyn Heights; and 5) the easternmost part of New Jersey across the Hudson River from the WTC (**Figure 2**). The women were evenly distributed (31-34%) for trimester of pregnancy on 9/11 .

We utilized questionnaires and a time-activity log to help characterize exposures from 9/11 until October 8, 2001. The questionnaire included items on sociodemographic characteristics, medical and pregnancy history, employment, potential home, work, food exposures to PAH (i.e. grilled foods and cigarette smoke), evacuation on 9/11 through the dust and debris, perception of air quality following 9/11, and presence of WTC dust in the home. The time-activity log recorded all the time spent indoors and outdoors at any distinct street address in one of 5 zones around WTC for 4 weeks after 9/11 (**figure 2**). These zones were defined by 5 different areas at increasing distances from WTC, which represented likely high exposures to emissions and dust depending upon the location and intensity of the WTC plume (emissions) and dust impact areas. The time spent outside any of the 5 zones was not recorded, but could be computed by subtraction. In separate analyses, no differences in exposure patterns were seen between indoors and outdoors, and therefore total time spent is used in the exposure analyses. The time-activity logs were geocoded using ArcGIS software (ESRI, Inc., Redlands, CA) based on each street address and daily time spent within these zones.

Beginning in February 2002, we obtained blood and urine specimens from 165 women, 33 of whom were in the 3rd trimester of pregnancy (the remainder had delivered), in order to determine levels of PAH-DNA adducts and other biomarkers of exposure. For 160 samples, DNA was successfully obtained from mononuclear cells by standard RNase and proteinase K treatment and phenol/chloroform extraction. Mononuclear cells have higher adducts than granulocytes (Jahnke et al., 1990; Savela and Hemminki, 1991), and thus this method should allow detection of adducts in women who were most heavily exposed to WTC fire emissions or dust. The half-life of PAH-DNA adducts in total white blood cells has been reported to be 3-5 months (Mooney et al. 1995), and the half-life of adducts in mononuclear cells should be no shorter than in total white blood cells. PAH-DNA adducts were measured by a competitive ELISA with chemiluminescence endpoint detection (Divi et al. 2002). Results were the average of triplicate measurements. For 7% of samples with sufficient DNA, samples were reassayed. Repeat analysis of 3 positive controls resulted in a CV of 22%. Samples with inhibition <20% were considered nondetectable. The LD was approximately 40 adducts/10^6 nucleotides (apmn, adducts per million nucleotides), based on 20% inhibition and 10 ug of DNA assayed per well. PAH-DNA adducts were categorized as below the LD, <60 apmn (median of detectable adducts), ≥60 apmn, and >100 apmn. This upper category was derived from a plot showing a marked shift in the cumulative distribution at this level (>92%).

In a randomly selected subset of 100 women, the Centers for Disease Control (CDC) determined that these women had metals in urine and blood, organochlorines (OC, including 40 polychlorinated biphenyls [PCB], 7 chlorinated dibenzodioxins [PCDD] and 10 chlorinated dibenzofurans [PCDF]) and and polybrominated diphenylethers (PBDE, including 8 congeners) in plasma. Random selection was done by assigning random number obtained using the SAS function to all 187 women, sorting on the random number, and choosing the first 100 women. Metals were measured in whole blood and urine using published methods (Date and Gray 1989; Nixon et al. 1999; Paschal et al. 1998;Guo T and Baasner J 1993). OC and PBDE were analyzed using high-resolution gas chromatography/isotope-dilution high-resolution mass spectrometry (HRGC/ID-HRMS) (Patterson, Jr. et al. 1991; Sjödin et al. 2004). Serum total lipids were calculated using the values for triglycerides and cholesterol assayed with an enzymatic method (Akins et al. 1989). Urinary creatinine was assayed using a kit from Sigma; the median was 0.43 g/L, the maximum 1.9 g/L; two values were below 0.01 g/L. Urine metals are presented uncorrected to allow comparison with previously reported data, but creatinine was included in the multivariate analyses.

Limits of detection (LD) for each biomarker are given in each Table. For metals and PBDE, laboratory values were censored at the LD. In parametric analyses we substituted the value LD/√2 for unreported metal levels. Because we focussed on OCs that were above the LD in more than 50% of the samples, univariate analyses of OC concentrations (4 PCBs, 2 dioxins and 2 dibenzofurans) changed very little whether LD values were assigned a censored value (LD/√2) or were the actual value reported. However, the measures of central tendency for concentrations of ΣPCB4/total (sum of PCB 118, 138, 153, 180 over total PCBs) were influenced by choice of surrogate value for the LD. Few samples had ΣPCB4 congeners below the LD, but many samples had values below the LD for other PCBs. As a result the ΣPCB4/total PCB decreased artificially when a surrogate value (LD/√2) was used. The mean ΣPCB4/total PCB increased by 40% and the median by 50% when using LD/√2 rather than zero or the actual value below the LD. Therefore, we used the actual values (which were all positive) or the lowest positive value (to avoid zeroes) of congeners for the sum of PCBs (see discussion and citations in references Berkowitz et al. 2003a and Fitzgerald et al. 2004). We could not use this approach for the PBDE, because the lowest positive value was usually higher than the lowest reported LD value. Therefore, as individual LD values were given, we used the median LD of all samples and substituted the median LD/$\sqrt{2}$ for LD-samples in parametric analyses.

A daily dust exposure index (EI) was estimated for each woman. The EI each day was derived by reconstruction of the post-9/11 WTC plume. The Computational Chemodynamics Laboratory (a research unit of the Exposure Measurement and Assessment Division of The Environmental and Occupational Health Sciences Institute, UMDNJ) developed simulations of the plume that was generated by the collapse of the WTC buildings and the subsequent fires at the site (Huber et al. 2004).

The plume reconstruction was obtained by generating a set of simulations that were the result of employing the Regional Atmospheric Modeling System (RAMS)/Hybrid Particle and Concentration Transport (HYPACT) which is employed as part of the Modeling ENvironment for Total Risk (MENTOR) developed by EOHSI. The RAMS/HYPACT model was used to reconstruct the atmospheric dispersion of "generic" particulate matter emitted from the location of the WTC. This simulation employed a triple-nested modeling domain of 4 km x 4 km (grid1), 1 km x 1 km (grid 2), and 250 m x 250 m (grid 3) resolutions. The RAMS/HYPACT results were averaged over time to produce 8-hour concentrations for 5 zones across lower Manhattan, Brooklyn, and New Jersey. A source decay factor was incorporated into each 8-hour concentration average estimate, corresponding to a sigmoidal weakening function. This was done to simulate the decrease in the intensity of the fires, etc. during the days after 9/11. The RAMS/HYPACT model accounts for advection, convection, and dispersion of emissions following the collapse of the towers, but not constructed for the initial wave of dust and debris. A GIS-based database developed by the US Environmental Protection Agency (USGS 2001) from overflight photos and satellite images provides approximate boundaries of dust/debris allowing characterization of the extent of the area of deposition from the WTC buildings collapse (USEPA 2002; USGS 2001). The GIS data were superimposed on the zones of concern to determine the relative impact of the dust and debris wave for use in the development of the EI for 9/11. The available images show that the dust/debris field completely covered zones 1 and 2 from September 11 through September 13, 2001. During this same time period, zone 3 was also heavily covered to an area within 300 feet of zone 2 boundaries. Most remaining suspended dust was settled and/or washed away after a rain event on September 14. For zone 1, zone 2 and the first 300 feet within zone 3 (nearest the zone 2 boundary), the airborne concentrations from resuspended dust/debris on September 11 through September 13 were estimated to be approximately equal to two-thirds of the maximum plume concentration. In the remainder of zone 3, this estimate was one-third of the maximum plume concentration (in each case, the maximum plume concentration is the maximum of the 8-hour average). These weighting factors were derived from visual inspection/interpretation of the available images of the WTC plume and debris and the relative intensity of plume and dust.

Reflecting the RAMS/HYPACT model start time of 9:00 a. m. EDT, only two 8-hour averages exist for 9/11. Therefore, the total number of hours per person was set to be equal or below 16 for 9/11. Because the activity diary for an individual does not include the specific hours spent in a particular zone in a particular day, the data sets cannot be used to directly estimate exposure based on the time of day. As a result, the daily average plume density in each zone was combined with the activity diary entries (i.e., time spent in each zone) in order to develop an average exposure index (EI).

The EI accounts for time spent both indoors and outdoors. Various indoor/outdoor (I/O) concentration penetration factors have been reported and used for microenvironmental models. These values typically range from 0.05-0.9 (Burke et al. 2001; Thornburg et al. 2001; Vette et al.

2001). To account for the type of building ventilation system (residential/non-residential), and a particle size range, an I/O ratio value of 0.15 was used.

The EI was calculated for 187 women for 9/11 and each of the 27 days immediately after. Because the exact emission amount resulting from the WTC collapse is unknown, a hypothetical unit pollutant release rate was used in RAMS/HYPACT simulation. The simulation with a unit release provides the relative "normalized" concentration of airborne contaminants at different locations. These calculations result in a dimensionless EI. Because the values are relative, identical EIs on different days may not represent exactly equivalent daily exposures. However, the potential misclassification was small enough to justify their summation. This was shown by the correlation of the daily median EI with EPA PM monitoring data at 4 sites (see Results). In addition, for most women, their exposure sums were dominated by the value on 9/11 or on a few other days with very high readings, because of the logarithmic nature of the EI distribution. Therefore, for the purposes of estimating total exposure, the indoor and outdoor EIs have been summed over certain time periods, with ΣEI being the 28-day (4-week) sum. If additional monitoring data become available from ongoing data analyses, the current EIs can be analyzed to determine if there is reason to improve the estimates and more accurately calibrate the EIs.

Statistical analyses were conducted using Excel and SAS PC v 9 (Cary, NC). The EIs were explored as continuous variables (daily values, weekly sums and 28-day total [ΣEI] for each woman), and as quantiles (dichotomized at the median). The significance of associations among categorical variables was assessed by chi-square analysis, using the Fisher-exact test and the Mantel-Haenszel test for trend where appropriate. As the exposure variables were not normally distributed, nonparametric methods (Wilcoxon rank-sum test and Kruskal-Wallis test) were used to test for differences in the medians between groups. Spearman correlations ($\mathbf{r_S}$) were used to examine associations between continuous variables. In addition, we used multivariate analyses to predict biomarker levels of those analytes that demonstrated any association with ΣEI (Pb, Hg, OCDD, ΣPCB4). For these models, the log-transformed biomarker level was the dependent variable, and the dependent variables were EI (dichotomized below or above the median ΣEI) and factors that might potentially affect selected biomarkers (age, body mass index, pregnancy at blood-draw, breast-feeding, smoking, race, and fish intake). We used the general linear models program (PROC GLM) in SAS with the LSMEANS option to determine whether the biomarker level differed significantly by ΣEI (below *vs*. above the median).

Results

Within this cohort of pregnant women, the majority of participants were located north and southeast of the WTC in zones 1-3 at 9 a.m. on 9/11 (**Figure 2**). Most women (133/187, 71%) were located within 8 blocks (zones 1-2), including 12 women who were in a WTC tower or the complex underneath. The locations of participants at 9 a.m. on 9/11 were: 40.6% in zone 1; 30.5 % in zone 2; 17.6 % in zone 3; 1.6% in zone 4; 0.5% in zone 5; and 9.1% who were not there but who re-entered the area within the succeeding weeks.

Regardless of their exact location at 9 a.m. on 9/11, most women either lived or worked in zones 1-5 before 9/11 (33 women both lived and worked there, 38 lived, and 113 worked there; three neither worked nor lived there). Therefore, although we do not have data on average time spent in these zones before 9/11, it is likely to be much higher than the durations reported in the 4 weeks after 9/11. As shown in **Figure 3a**, women reported little time in zones 1-3 immediately following 9/11, gradually increasing thereafter with notable dips on the weekends. During the first week after 9/11, 37% of women spent some time in zones 1-3, and the percentage rose over the next three weeks (42, 61, 70%). During the month after 9/11, women spent more time in zones 2 and 3 than in zone 1, which was quite inaccessible at this time. The average duration in zone 3 was 1.2 hr/d in the week immediately after 9/11, rising gradually to 3.3 hr/day for the third work-week (Monday-

Friday) in after 9/11 (mean hrs/d by zone are shown in **figure 3a**); time spent in zones 1 and 2 was similar in later weeks, but lower than zone 3 in the early weeks. Over the same period, average time in zone 1 was 0.2 hr/d in week 1 and 1.2 hr/d in week 3. Patterns of time spent in zones 1-5 did not differ materially with regard to whether women lived and/or worked in lower Manhattan.

In contrast to the increasing time-spent in zones 1-3, the relative dust concentrations within the five zones declined rapidly during the 28 days after 9/11 (**figure 3b**). However, marked fluctuations in the dust and emission levels existed, consistent with changing construction, traffic and weather patterns over this period (Dalton 2003; Landrigan et al. 2004). The individual EIs in **figure 3c** were computed by combining individual-level data of the kind in **figures 3a** and **3b**. The daily EIs exhibit a steep decline during the 3 days after 9/11, lower EIs at the weekends after that, and a slight shift toward increasing levels (but well below those of the first 3 days) in weeks 3 and 4, consistent with the reported time spent in zones close to the WTC in **figure 3a**. The daily relative dust levels in zone 1 (**figure 3b)** were correlated with particulate concentrations at 4 stations close to the WTC that monitored PM after September 22, 2001 (Columbia University 2003) (Chambers Street [PM10 r=0.91, PM2.5 r= 0.93], 290 West Broadway [PM10 r=0.73], West Broadway-Park Place [PM2.5 r= 0.68]; N=7-15 per site). Using the models of reported PM data tested for performance against daily EI **(**i.e. **figure 3b)**, we estimated the daily median PM2.5 or PM10 levels in zone 1 by extrapolation to have been >1000 ug/m^3 on 9/11 and >100 ug/m^3 from 9/12 to 9/16/2001 in some locations (data not shown).

Sociodemographic factors did not differ by the ΣEI (28-day total) among participants (**Table 1**). The cohort is 35 years old (mean), largely White, married, highly educated, and non-smoking. Women who both worked and lived in lower Manhattan on 9/11 (n=33) had a higher ΣEI than women who only worked (n=113) or only lived (n=38) or spent time in one of the zones for other reasons (n=3) (**Table 1**). Answers to exposure-related questions about when and where women lived were strongly correlated with ΣEI, as expected from the congruity of these questions with data in the time-activity log (selected exposures are presented in **Table 1**). Notably, evacuation through the immediate area on 9/11 led to a higher ΣEI. The median day's EI for 9/11 was 3.2 among 85 women who evacuated through the WTC debris; the 9/11 day's EI was higher among women who remained in the debris 40+ minutes (median EI 3.7 on 9/11, N=40) than than those who stayed for 1-39 minutes (median EI 2.6 for 9/11, N=45), or not at all (median EI 1.3, N=102; $p<0.0001$). Women who wore dust masks during cleaning also had higher EIs, although the reported presence of dust in the home was not associated with EI.

The pattern of EI vs. time as shown in **Figure 3c** is explored in relation to perceived air quality (PAQ) in **Table 2**. Here, in week 1, the 7-day EI-sum was not related to PAQ, and this was probably because few women reported spending much time in the area during week 1 (39/185, 21%). During weeks 2-4 post 9/11, a strong association was observed between perceived air quality and weekly EI-sum, as women who worked or lived in lower Manhattan returned to the area (**Table 2**). The association between PAQ and ΣEI existed for all women in weeks 2-4 and among just those women who reported spending most of their time in zones 1-5 (i.e. 49% in week 2, 69% in week 3, 77% in week 4; n=39, 92, 127, 143 respectively).

PAH-DNA adducts were measured in 160 women. Most were non-detectable (88/160, 55%); the median of detectable values was 60 adducts/10^6 nucleotides (apmn). Eleven women had levels higher than 100 apmn, and nine of these women had blood drawn in February or March, 2002 (**Table 3**), a time interval within the reported clearance times in of PAH-DNA adducts from lymphocytes (Mooney et al. 1995). Samples collected in February/March had a significantly greater number of detectable PAH-adducts (46; 64%) and a higher median value (46.7 apmn) compared with later samples (26, 30%; median 20.0 apmn; $p<0.0001$ **Table 3**). There were no consistent associations between PAH-adducts and EI, when considered overall or by various temporal windows of blood draw and EI-weekly sum. Neither ΣEI nor PAH-adducts were associated with dietary intake of foods that may contain PAH (e.g. broiled meat) or smoking, questions targetted for this purpose in the questionnaire.

Thirteen urinary metals as well as Pb, Cd, and Hg in blood were measured in a subset of 100 women. After comparing the percentage detected and the median values of the urinary levels in our data with earlier reports (Centers for Disease Control and Prevention 2003; Edelman et al. 2003), we present findings on urinary Sb, Cd, Pb, and U, and blood Pb and Cd for which levels were reported among firefighters exposed at the WTC (Edelman et al. 2003). We also included urinary Co because levels were weakly correlated with ΣEI. We included blood Hg because levels in the women were higher than in the NHANES data and because Hg was reported as a possible WTC site contaminant (Edelman et al. 2003). None of the other urinary metals was associated with ΣEI, either among all women or among the February/March biospecimen collections. Moreover, the observed correlations with ΣEI, that were significant among 100 urine samples ($\mathbf{r_S}$ 0.20 for Co and 0.21 for Pb, $p<0.05$), were not significant among the February/March biospecimens ($\mathbf{r_S}$=0.13 and 0.12, respectively, $p>0.3$; n=44). The median values of four urine metal concentrations in Table 4 were lower than those reported in WTC-exposed or control firefighters (urinary Co was not reported). The medians of Co, Cd, and U were lower than among females in the NHANES data (Centers for Disease Control and Prevention 2003), while urinary Pb was higher (**Table 4**). Blood Cd was significantly correlated with ΣEI ($\mathbf{r_S}$=0.29, p=0.01), but the comparison with ΣEI above and below the median was not significant for any of these (Kruskal-Wallis). No significant associations of blood metals with exposure were seen among the February/March biospecimens.

Selected organohalogen compounds (40 PCBs, 7 PCDD, 10 PCDFs, 8 PBDEs) were measured in blood plasma in the same randomly selected subset of 100 women as were the metals. Data on specific PCBs, PCDFs PCDDs and PBDEs presented in **Table 5** were chosen because they were detected in >50% our samples, or they were reported in WTC-debris (PCBs, 2,3,4,7,8-pentaCDF, PBDEs; Litten et al. 2003; Offenberg et al. 2003), or they were elevated in serum among firefighters (Edelman et al. 2003). PCB and OCDD levels were not significantly higher among women whose ΣEIs were above the median, and none of the other OCs or PBDEs differed significantly with respect to median ΣEI. In comparison with other reports, the median 1234678-heptachlorodibenzodioxin level (30 pg/g) was similar to the adjusted geometric mean reported in exposed firefighters (28 pg/g lipid, Edelman et al. 2003). 1234678-CDF levels were higher in exposed firefighters, but no levels were reported. 23478-CDF was below the limit of detection in 59% of our sample. Two other OCs were detectable in more than 50% of the women, including 123678-CDD (median 22 pg/g) and OCDD (median 224 pg/g); levels were not reported for the firefighters. There were no significant associations between PBDEs and ΣEI.

Multivariate analyses were undertaken to evaluate the association of analytes that showed some pattern of association with ΣEI, by computing the geometric means of the biomarker (dichotomized above *vs.* below the ΣEI median) adjusted for age, non-White race, being currently pregnant, breast-feeding, BMI, and smoking. Models for PCBs and Hg were also adjusted for fish intake. No significant differences were found in the adjusted geometric means with regard to dichotomized ΣEI for PCB, OCDD, PBDEs, Pb (blood and urine), Cd, or Hg among all 100 women tested or among the 44 women who donated blood samples in February and March, 2002.

Discussion

The predominant air pollutant at the WTC was dust of large-size particles (>10 u)(Lioy et al. 2002). Air monitoring conducted in the vicinity of the WTC after September 25, 2001 revealed elevated levels of PM10 and PM2.5 as close as 6 blocks northeast of the site (**figure 1**). Daily PM2.5 measured 5 blocks east of the site from 9/14-10/16/2001 was 15-60 ug/m^3 (Landrigan et al. 2004). At the end of September, 2001, when more air monitoring had commenced, median levels of PM2.5 were >60 ug/m^3 (1-2 blocks away). At Chambers Street (6 blocks north-northwest), the median PM10 was 43, and PM2.5 10 ug/m^3 in October 2001. At 290 Broadway (6 blocks northeast), median PM2.5 was 22 ug/m^3 in late September (N= 4 days) and 15 ug/m^3 in October, while PM10 was 32 and 30 ug/m^3 during those time periods, respectively. However, daily excursions of PM10 and PM2.5 near or higher than 100 ug/m^3 occurred periodically, depending on site operations, weather and traffic (Columbia University 2003; Dalton 2003; Vette et al. 2001). Some distance away at Canal Street (15 blocks or about 0.7 miles north), levels were lower (median PM2.5 14.3 ug/m^3 in September, 12.5 ug/m^3 in October 2001). At PS64 (Public School 64, about 50 blocks northeast) levels were 11.2 ug/m^3 in September, 13.8 ug/m^3 in October 2001 (median), which is similar to annual data (13.5 ug/m^3 in 2001, 12.1 ug/m^3 in 2002 at PS64). Women in our cohort in zone 1 were probably exposed to >100 ug/m^3 of particulates on 9/11-9/12, based on our extrapolation PM2.5/10 from the daily EI correlations with the air monitoring data. The EPA 24-hour standard is 65 μg/m^3 for PM2.5 and 150 μg/m^3 for PM10 (U.S. EPA 1997).

As the dust exposures in lower Manhattan gradually diminished in weeks 1-4 post-9/11, women gradually returned to that area for longer time periods. Therefore fluctuation in the daily EIs (**figure 3**) reflects personal activity patterns (which increased) as well as well-known changes in pollution sources and pollutant levels in lower Manhattan during this period (Dalton 2003). Consistent with the temporal decline in particulate levels, the median daily EI in our population decreased by 10-100-fold over the first few days (**figure 3c)**. After 9/14/2001, the median of non-zero reconstructed daily relative dust levels remained below 0.01 (the nominal detection limit) (see **figure 3b)**. The significant association of EI with questionnaire data on exposure and air quality indicates that personal recollection may be a reasonable way to estimate a person's relative exposure intensity in lower Manhattan post-9/11. For the events of 9/11, these results are reasonable because the magnitude of the changes in pollutant levels by day and by geographic location was large. Therefore individual exposure to WTC contaminants can be ranked by assessing perceived air pollution as well as information from time-activity logs and GIS-based exposure modeling. Uncertainties exist in our exposure estimates, including the recall data and the plume reconstruction. Recall information was used to derive the GIS time-activity variables and to obtain data on perceived air quality from the exposed women. Plume reconstruction was used to calculate the GIS dust exposure levels. There were no air monitoring data during the first 24 hours after the events of 9/11, and the plume dust level estimates for the GIS were evaluated for precision during that time using plume density derived from satellite photographs.

The highest levels of PAH-DNA adducts were found in women whose blood was collected closest to the date of 9/11, but no association was found with ΣEI. PAH exposure around the WTC is known to have been significant (Landrigan et al. 2004). Extremely high levels of PAH were found in settled dust (Lioy et al. 2002; Offenberg et al. 2003), and estimated air levels were >10 ng/m^3 in the PM2.5 fraction soon after the incident compared with <1 in normal urban air and in the plume later on (Pleil et al. 2004).

Our data for each woman's EI and zone locations were available for the day of the event through October 8, 2001, the time when peak exposures occurred around the WTC. PM and PAH levels were highest during the first 36 hours after 9/11 (Offenberg et al. 2003). However, airborne PM and PAH levels were elevated for some time after 9/11 (Pleil et al. 2004; Swartz et al. 2003). Therefore PM and PAH exposures were greater in weeks 3 and 4 than in week 2, because women spent more time in the affected area as time went on. This pattern may reflect seasonality of PAH emissions, as recent New York City personal air monitoring data suggest (Perera et al. 2004). However, other studies that have found higher PAH levels in winter had marked differences only in highly polluted areas (Perera et al. 1992; Topinka et al. 2000). With urban or tobacco smoke exposures, the PAH-DNA adducts were only slightly higher in winter than summer (Georgiadis et al. 2001).

Metals were reported to be elevated at the WTC site debris by some but not all investigators. Blood lead and urine Sb were higher in exposed than control firefighters while urine Cd was higher in more heavily than less heavily exposed workers (Edelman et al. 2003). When adjusted for potential confounders, we found no significant associations between metal biomarkers and EI or timing of the blood draw closer to 9/11. Other than blood-Hg, metal levels in these women were not higher than among the firefighters or females in NHANES. Moreover, the adjusted geometric mean for blood Hg was identical to that in the NHANES females (0.9 ug/L; see Table 4) and in women of reproductive age in NHANES (1.0 ug/L; Schober et al. 2003). Although these comparisons are helpful in understanding our exposure data, they should be interepreted with caution inasmuch as the three groups are very different demographically and geographically.

Organochlorines were abundant at the WTC site and in run-off from the site (Lioy et al. 2002; Litten et al. 2003; Offenberg et al. 2003), and the compounds found at the highest levels in environmental samples were those consistent with combustion products. Similarly, elevated levels of 1234678-CDD and –CDF were reported in the most highly exposed firefighters examined (Edelman et al. 2003). In our study group, there were no significant associations between OCs and EI. The PCB levels are quite similar to levels reported in several recent studies, especially considering the differences in the populations and the laboratories performing the analyses. For example our median ΣPCB4 level (83 ng/g lipid) is lower than in a New York City cohort of pregnant women who were younger (median 151 ng/g lipid, mean age 25 yrs; Wolff et al. 2005). Another northern New York cohort had similar levels (geometric mean 1.2 ug/L, estimated to be 150 ng/g lipid based on 8 g/L plasma lipids in pregnant women (Longnecker et al. 2003), mean age

26 yr; Fitzgerald et al. 2004). Finally, levels are similar to those found in two breast milk pools from California and North Carolina, collected in 2002-2003 from mothers approximately 30-years old (Wang and Needham 2003).

Levels of 23478-CDF were unusually high in the WTC outfall (Litten et al. 2003); this compound was not detectable in 59% of our women, although it has usually been found in breast milk at levels equal or higher than 123678-CDD and 1234678-CDD/F (Focant et al. 2002; Glynn et al. 2001; Yang et al. 2002). Other detected dioxins and dibenzofurans found by us (123678-CDD, 1234678-CDD/F and OCDD) are also widely detected and are the highest detected congeners in breast milk (Focant et al. 2002; Glynn et al. 2001; Schaum et al. 2003; Schecter et al. 2002). Their relative proportions (i.e. OCDD>1234678-HpCDD>123678HxCDD) are similar to those proportions among the WTC women in our cohort, even where levels were much higher (Yang et al. 2002). Furthermore, the proportions are similar to those reported from California and North Carolina 30-year old mothers (Wang and Needham 2003), although median levels in our mothers were higher (e.g. OCDD in the pool from California was 42 pg/g lipid and from NC was 84.6 pg/g). This would not be attributable to age or other factors, given the effect-sizes in in our multivariate models (data not shown). PBDEs in our samples were somewhat lower than those reported in two milk pools (Wang and Needham 2004), but the proportions were very similar.

Our data show only a weak association of OCs with WTC-derived exposure in the month after 9/11. Levels are similar to firefighters with demonstrated elevations, and levels are higher than reported in recent national data (Centers for Disease Control and Prevention 2003). Therefore some of these compounds might have been absorbed by bystanders and firefighters in lower Manhattan after 9/11. However, the levels might not be high enough to show relationships with exposure because the WTC-increment over existing body burden is not detectable. For example if the native body burden is 20 pg/g lipid, a pregnant woman would have 600 ng total in 30 kg adipose and circulating lipid. To see an increase in level, an absorption of 120 ng would be required, based on 20% precision in the measurements (laboratory and population variation). Our population was in varying stages of pregnancy and post-delivery at blood collection time, which greatly complicates interpretation of biomarker data, including metals and persistent organic compounds.

In summary, we were able to successfully incorporate results of a WTC-plume-reconstruction model into predicted exposures and doses of airborne emissions among these women who were near the WTC immediately after 9/11. The results provided daily estimates of exposure by utilizing both geographic dust concentrations and individual activity patterns to predict individual EIs among 187 women for 28 days. Women experienced very high dust exposures; as a result of being close to the WTC in September 2001, the particulate matter exposures were likely in excess of 100 ug/m^3 for women exposed immediately after 9/11. Higher PAH-DNA adducts were found in blood samples collected closer to 9/11, and personal perception of air quality was associated with relative dust levels estimated from plume reconstruction (EI).

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Table 1. Selected Demographic Factors and Activity Patterns among 187 Participants in the Mount Sinai WTC Pregnancy Study by 28-Day Exposure Index (ΣEI) derived from Plume Reconstruction Data

	Exposure Index (ΣEI), Sum of 28 days			
	ΣEI < median	ΣEI ≥ median	Total	P (X^2)
Interview_age	N	N	N	
<25	1	1	2	
25— 29	19	8	27	
30— 34	30	43	73	
35— 39	34	28	62	
40+	9	14	23	0.12*
Race				
White	70	64	134	
Black or African American	9	11	20	
Asian	2	6	8	
Hispanic	5	8	13	
Other (mixed)	7	5	12	0.48
Marital Status				
Married	83	83	166	
Living with the baby's father	7	7	14	
Never married/separated/divorced	3	4	7	0.93
Education				
Some High School/High school	4	5	9	
Some college	12	12	24	
Bachelor's degree (grades 13 - 16)	31	27	58	
Some graduate school (grades 17+)	4	5	9	
Master's degree	25	23	48	
Doctoral degree (JD, MD, PhD, etc)	17	22	39	0.33*
Smoking at time of blood draw				
No	87	90	177	
Yes	6	4	10	0.50
Worked or Lived in lower Manhattan before 9/11				
Work near WTC	59	54	113	
Live near WTC	22	116	38	
Live and work near WTC	9	24	33	0.019[a]
Neither work nor live near WTC	3	0	3	0.009[b]
Evacuation through debris on 9/11				
Did not evacuate through debris	66	36	102	
1-39 min	20	25	45	
40+ min	7	33	40	<.0001
Dust in home?				
Yes	25	28	53	
No	7	10	17	0.67
Dust removal method				
Wet cloth	4	4	8	
Both wet cloth and wet mop	14	20	34	
Don't know	7	5	12	
None of the above	2	3	5	0.76
Did you wear a dust mask while cleaning?				
Yes	10	24	34	
No	21	11	32	0.003

The median ΣEI for 187 women was 2.66 (relative dust exposure). P is for X^2 . * notes a test for trend. + notes Fisher exact test.

[a]P=0.019 refers to the X^2 test of the 3 categories of women who worked or lived near the WTC.

[b] P=0.009 compares all 4 categories, using Fisher's exact test.

Table 2: EI (dust intensity) in relation to perceived air quality score in lower Manhattan, by week post 9/11

Perceived air quality (PAQ) score in lower Manhattan (PAQ range 1-8, N=185)	**Week 1** (EI median=2.45)				Week 2 (EI median=0.016)				Week 3 (median=0.13)				Week 4 (EI median=0.11)			
	N< median	N≥ median	%≥	Total	N< median	N≥ median	%≥	Total	N< median	N≥ median	%≥	Total	N< median	N≥ median	%≥	Total
Those who spent most of their time in zones 1-5																
Very hazy/smoky to dense/visible haze/smoke with bad smell during some/most of the time (PAQ 3-4)	**12**	**16**	*57*	28	**10**	**62**	*86*	72	**25**	**64**	*72*	89	**28**	**56**	*67*	84
None to rarely visibly hazy or smoky with none to occasional bad smell (PAQ 1-2)	**3**	**8**	*73*	11	**7**	**13**	*65*	20	**15**	**23**	*61*	38	**24**	**35**	59	59
Those who did not spend most of the week in zones 1-5 (PAQ not applicable)	**77**	**69**	*47*	146	**75**	**18**	*19*	93	**52**	**6**	*10*	58	**40**	**2**	*5*	42
p-value *		0.19		185	<.0001			185	<.0001			185	<.0001			185
Women who spent most of their time in zones 1-5 during the given week after 9/11 (N)	39				92				127				143			
Mean PAQ Score (sum of week's air (mean ± SD) quality at work and/or home)	3.3 ± 1.5				3.4 ± 1.2				3.1 ± 1.1				2.9 ± 1.2			
Mean ΣEI for week (mean ± SD)	3.92 ± 3.39				0.086 ± 0.15				0.22 ± 0.20				0.22 ± 0.20			
Spearman corr of ΣEI with PAQ Score (R_S)	0.074 p=0.66				0.288 p=0.005				0.219 p=0.013				0.308 p=0.0002			
Women who worked or lived in zones 1-5 on 9/11 including those who did not spend much time there in the 4 weeks after 9/11 (N)	*185*				*185*				*185*				*185*			
ΣEI for week (mean ± SD)	2.87 (2.54)				0.051 (0.115)				0.16 (0.19)				0.18 (0.20)			
(median)	2.45				0.016				0.13				0.11			

Two women who did not live or work were not present in zones 1-5 on 9/11 were excluded from the analyses for this table.

* P-values are for Chi-square,and were identical for the Mantel-Haenszel (trend test). In the 4-week analses for PAQ *vs*. weekly EI, the P-values for the two groups with PAQ values 1-2 and 3-4 (2x2 tables) were 0.37 (n=39), 0.031 (n=92), 0.21 (n=127), 0.37 (n=143).

Table 3: PAH-DNA adducts among 160 mothers in the Mount Sinai WTC pregnancy study

		All mothers		Biospecimens collected in: Apr-Oct 2002		Feb-Mar 2002		by ΣEI (median=3.30) Feb-Mar specimens			
								< median ΣEI		≥ median ΣEI	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**(%)**	**N**	**(%)**
PAH-DNA	**ND**	**88**	55	**62**	70	**26**	36	**11**	15	**15**	21
Adducts	**<60**	**36**	22	**14**	16	**22**	31	**14**	20	**8**	11
(per 10^6	**60-100**	**25**	16	**10**	11	**15**	22	**6**	8	**9**	12
nucleotides)	**>100**	**11**	7	**2**	2	**9**	11	**5**	7	**4**	6
	total	**160**	**88***	**72***	**36**	**36**					

ND=Not detected.

*Distributions are significantly different, χ^2 P<.001

Table 4: Blood and urinary biomarkers for metals among 100 mothers in the Mount Sinai WTC pregnancy study

Urinary Metals ug/L[a]	All Mothers Tested N=100		Feb-Mar 2002 Biospecimens N=44		median < or ≥ median ΣEI (3.62) N=44 [b]		WTC exposed firefighters {EDELMAN2003} GM, adjusted		NHANES females {CDC2003} median
	Median	**% ≥LD**	**Median**	**% ≥LD**	**< median ΣEI**	**≥ median ΣEI**	**Control**	**Exposed**	
Pb	**0.82**	94	**0.78**	98	0.75	0.89	1.0	1.2	0.60
Co	**0.32**	96	**0.38**	100	0.35	0.40	n.s.		0.41
Cd	**0.22**	98	**0.20**	98	0.24	0.19	0.38[c]	0.32	0.34
Sb	**<LD**	27	**<LD**	34	<LD	<LD	0.16*	0.20*	0.12
U	**<LD**	53	**0.0055**	52	0.0055	<LD	0.0075 [d]	0.0061	0.006

Blood Metals ug/L[e]	**N=100**		**Feb-Mar specimens [f]** N=44		N=44		GM, adjusted		
	Median	**% ≥LD**	**Median**	**% ≥LD**	**< median ΣEI**	**≥ median ΣEI**	**Control**	**Exposed**	median
Pb	**17**	100	**16**	100	16	16	19*	28*	13
Cd	**0.30**	71	**0.30**	55	0.30	0.22			0.3
Hg (total)	**3.2**	100	**2.2**	100	2.4	2.2	"not higher"		0.9

LD=Limit of detection. Metals were done in a random subset of 100 women, of whom 44 gave specimens in Feb-Mar, 2002, the remainder thereafter.

* p-value <0.05

[a] Elemental symbols for metals are Pb=lead, Co=cobalt, Sb=antimony, Cd=cadmium, U=uranium. LDs for metals in urine were Pb 0.3, Co 0.08, Sb 0.07, Cd 0.06, U 0.005 ug/L.

[b] Metals were not significantly different in this analysis for < vs ≥ EI with all or with 44 samples, both median tests (Kruskal-Wallis) and trend (Maentel-Haenszel). There were 22 samples each in the < and ≥ median ΣEI groups.

[c] Urinary Cd was higher in more- than in less-heavily exposed FF, although all-exposed were not higher than control.

[d] Urine U was higher in more- than in less- heavily exposed FF, although this difference was not statistically significant.

[e] LDs for metals in blood were Pb 3 ug/L, Cd 0.2 ug/L, total mercury (Hg) 0.2 ug/L..

[r] Metals were not significantly different in this analysis for < vs ≥ EI with all 100 or with 44 samples collected in Feb-Mar 2002, both median tests (Kruskal-Wallis) and trend.

Table 5: Plasma organochlorines and polybrominated diphenyl ethers (PBDEs) among 100 mothers in the Mount Sinai WTC pregnancy study

	All Mothers N=100		Feb-Mar 2002 Biospecimens N=44		by ΣEI < or ≥ median (2.66) N=100		WTC exposed firefighters {EDELMAN2003} GM, adjusted		NHANES {CDC2003} median
Serum organochlorines [a]	Median	% ≥LD	Median	% ≥LD	<median ΣEI	≥ median ΣEI	Control	Exposed	females
ΣPCB4 ng/g lipid [b]	**84**	94	**82**	93	**81**	**92**	[c]		**<LD**
23478-PeCDF pg/g lipid	**LD (4.0[d])**	41	**<LD**	50	**<LD**	**<LD**			<LD (4.8)
123678-HxCDD [e] pg/g lipid	**22**	80	**22**	89	**21**	**22**			<LD (7.5)
1234678-HpCDD [f] pg/g lipid N=99	**30**	97	**24**	95	**31**	**29**	**19***	**28***	<LD (24.7)
1234678-HxCDF [g] pg/g lipid	**7.2**	79	**6.2**	84	**7.6**	**6.7**	*[h]		<LD (5.2)
OCDD [i] pg/g lipid	**224**	95	**214**	98	**206**	**236**			<LD (145)
Serum PBDEs									
BDE-28 [j] ng/g lipid	**0.65**	59	**0.38**	50	**0.72**	**0.55**			
BDE-47 [k] ng/g lipid	**9.7**	96	**8.7**	93	**9.1**	**10.2**			
BDE-99 [l] ng/g lipid	**1.5**	70	**1.1**	61	**1.5**	**1.5**			
BDE-100 [m] ng/g lipid	**1.8**	96	**1.5**	95	**1.5**	**1.9 females**			
BDE-153 [n] ng/g lipid	**1.8**	98	**2.1**	100	**1.7**	**2.2**			

LD=Limit of detection. ΣPCB4 is the sum of PCB#118,138,153,180. Organochlorines were done in a random subset of 100 women, of whom 44 gave specimens in Feb-Mar, 2002, the remainder thereafter.

* p-value <0.05

[a] OC and PBDE levels did not differ significantly by date of collection or by ΣEI. P-value (Kruskal-Wallis) were all >0.2 by median ΣEI; the Pearson correlation coefficients were not statistically significant. (p>0.05). Multivariate analyses predicting the OC/PBDE levels by the median ΣEI adjusting for covariates did not change the significance of the associations. There were 50 samples each in the < and ≥ median ΣEI groups.

[b] Median of ΣPCB4 without lipid-correction was 0.46 ug/kg. LD for ΣPCB4 was 29 ng/g lipid.

[c] Not different from controls; values not reported by Edelman et al. 2003.

[d] Median of all LD values; range of LDs was 1.8-11 pg/g.

[e] LD 6.2 pg/g lipid (median of LDs for all such individuals; range 3.1-18 pg/g).

[f] LD 7.2 pg/g, range 3.9-20.

[g] LD 4.9 pg/g, range 2.6-14.

[h] 1234678-HpCDF in the FF study was more prevalent among all-exposed vs. controls (rates not given in paper; adjusted OR 3.5 CI 1.4-9.0 for exposed) (Edelman et al. 2003).

[i] LD 78 pg/g, range 36-240.

[j] LD 0.4 ng/g lipid (median of LDs and LQs for all such individuals; range 0.3-0.7 ng/g lipid)

[k] LD 2.0 ng/g, range 1-4.

[l] LD 1.0 ng/g, range 0.4-3.

[m] LD 0.5 ng/g, range .5-6 (n=3).

[n] LD 0.4 ng/g, range .3-5 (n=2).

LEGENDS FOR FIGURES

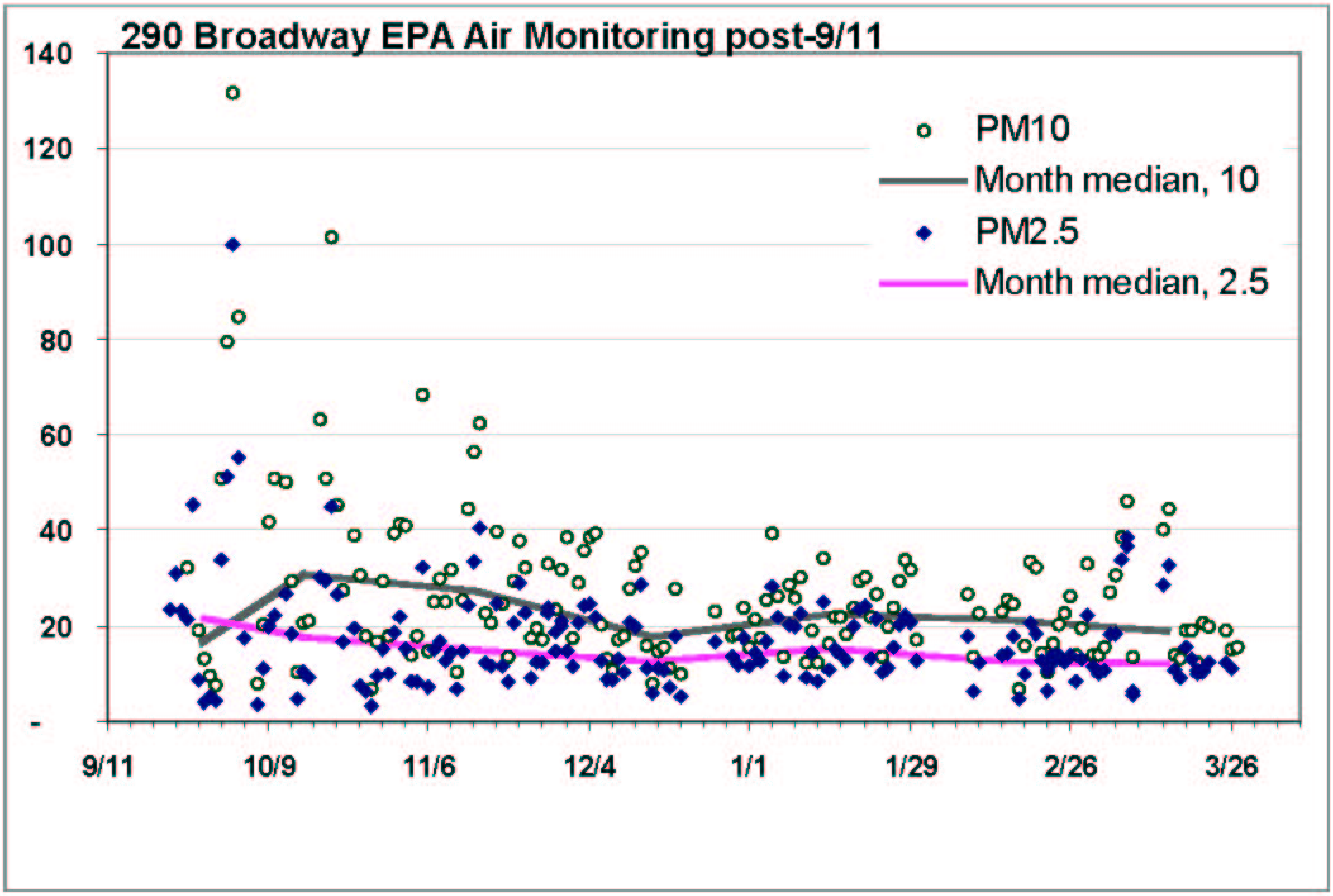
Figure 1: EPA particulate air monitoring approximately six blocks northeast of WTC (290 Broadway) from September 25 – March 26, 2002. PM10, N=169; PM2.5, N= 181 days. (data retrieved from: Columbia University, 2003; US EPA 2003).

Figure 2a: The five exposure zones were: 1) South of Murray Street; 2) South of Chambers Street and North of Murray Street; 3) South of Canal Street and North of Chambers Street; 4) Brooklyn Heights; and 5) the easternmost part of New Jersey across the Hudson River from the WTC.

Figure 2b: Location of 166 women study participants who were in zones 1-3 at 9 a.m. on 9/11/2001. WTC is the blank trapezoid just south of Vesey Street.

Figure 3: Duration and levels of exposure among 187 women participants from 9/11/2001 until 10/09/2001. (**3a**) Average time spent in zones 1-3. Average time spent in zones 4-5 (not shown) was less than 0.7 hr/d on any day. (**3b**) Relative intensity of dust exposure in each zone for the same time period, derived from plume reconstruction. Values less than 0.01 were considered below the limit of reliable estimate. (**3c**) Exposure Index (EI) for each woman are individual values computed from relative intensity (**3b**) and time spent at all street addresses within zones 1-5 over this time period (**3a**). The solid line in **3c** connects the median of non-zero EI values for each day. The numbers at the bottom of figure **3c** are the N of women whose EI was zero on this day. SS=Saturday, Sunday; weekend dates were 9/15-16, 9/22-23, 9/29-30, 10/6-7 in 2001.

Figure 1



290 Broadway EPA Air Monitoring post-9/11
PM10
Month median, 10
PM2.5
Month median, 2.5
140
120
100
80
60
40
20
-
9/11
10/9
11/6
12/4
1/1
1/29
2/26
3/26

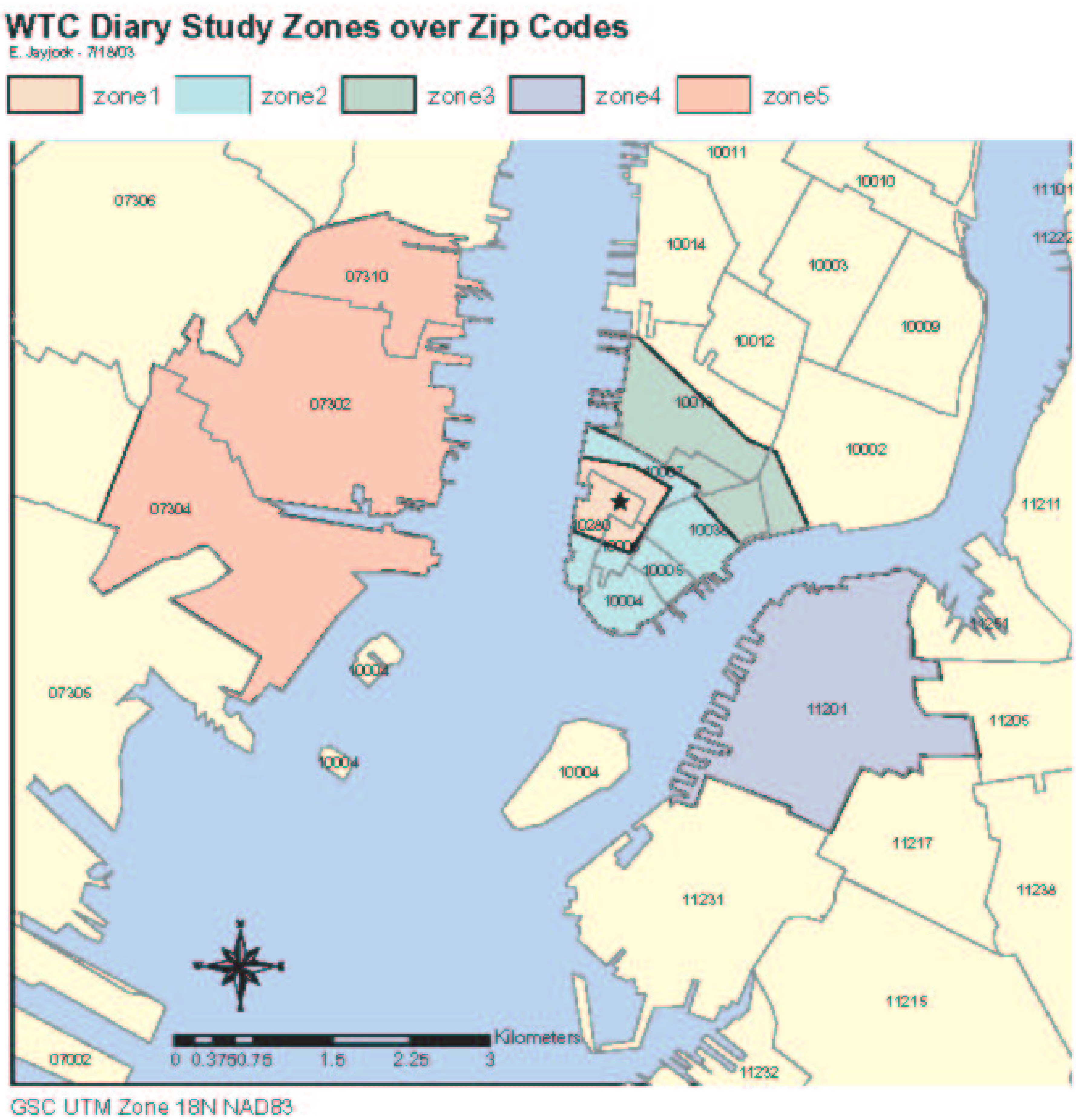


Figure 2a

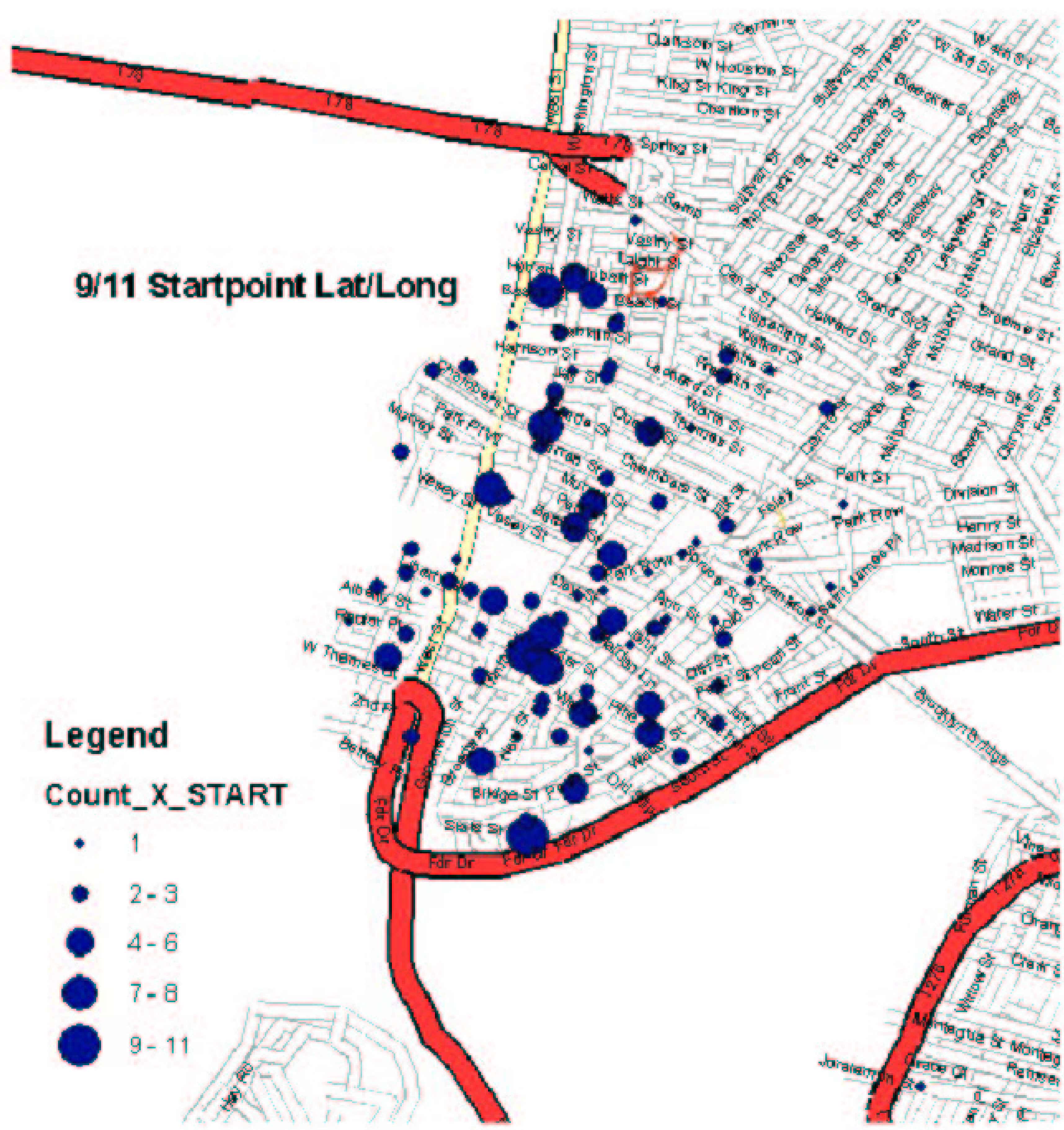
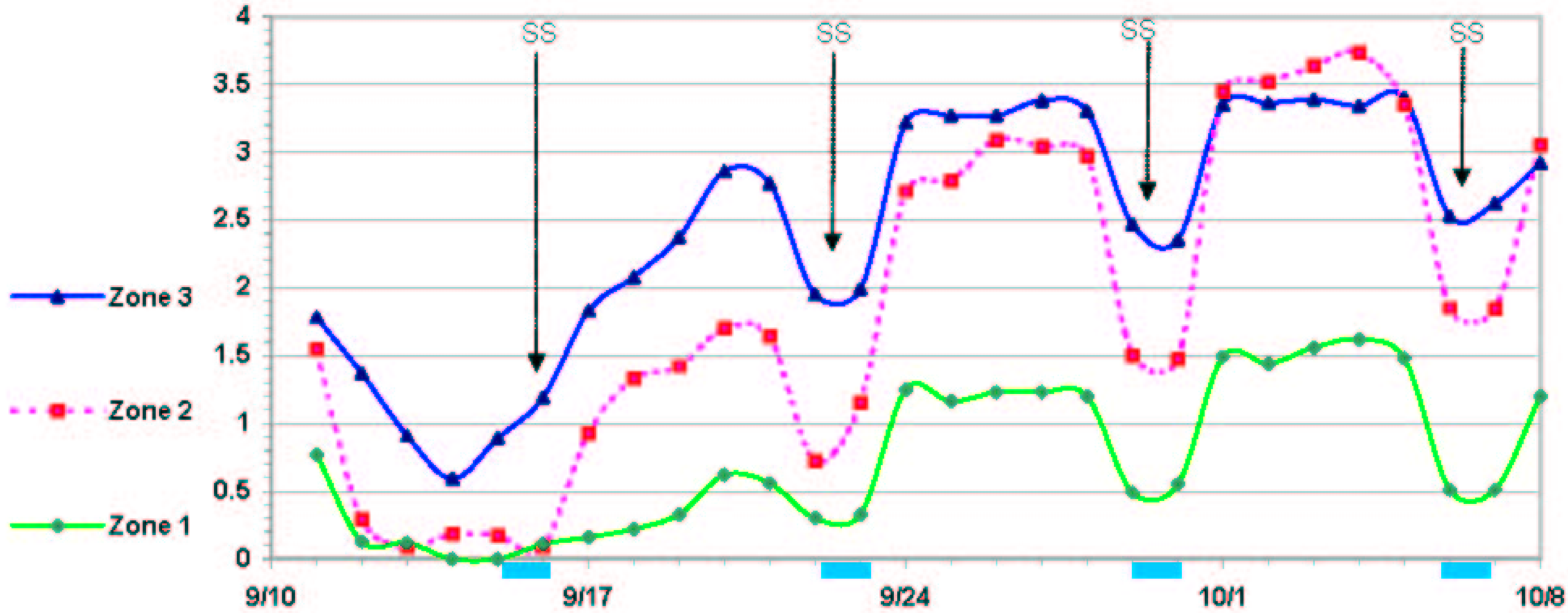
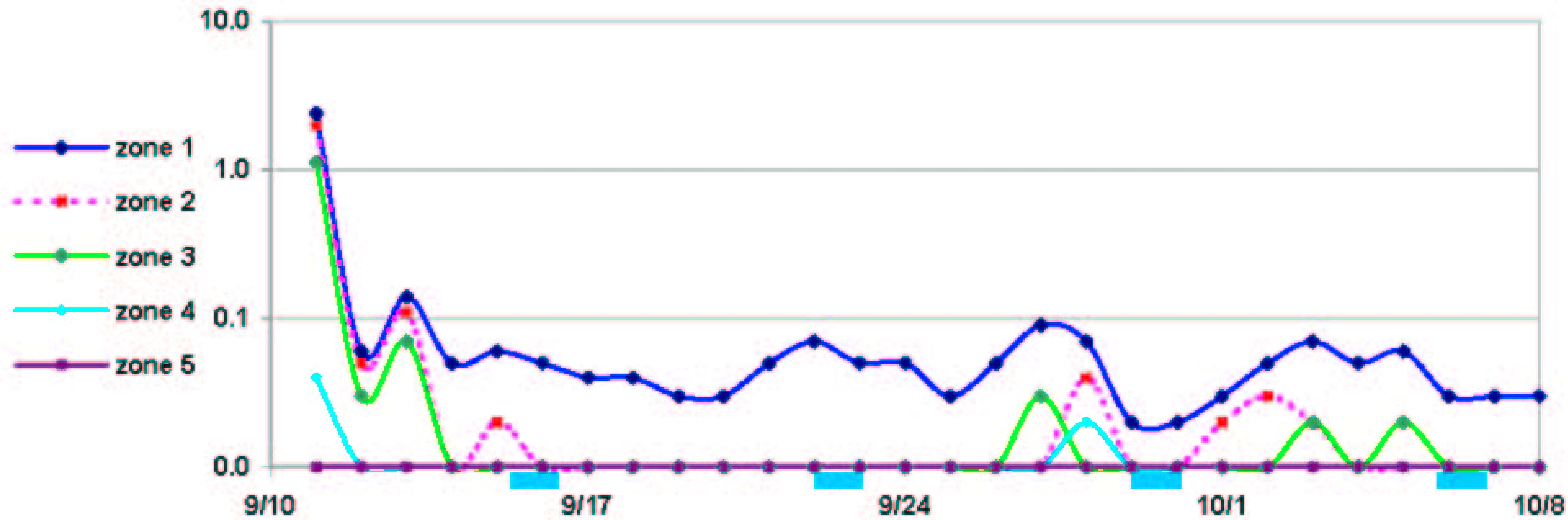


Figure 2b

3a. Average time per day (indoor and outdoor combined) spent by women in zones 1-3



3b. Reconstructed relative dust concentration in zones



3c. Individual Daily Exposure Index Values for All Women (N=187)